

Two- and Three-Dimensional Analytical Microscopy with Ions, Electrons and Photons

Igor V. Veryovkin, C. Emil Tripa, Wallis F. Calaway, and Michael J. Pellin
Materials Science Division, Argonne National Laboratory

Motivation

- Future nanotechnology applications will require metrology with sensitivity and accuracy unachievable with existing analytical instrumentation.
- Development of new metrology tools is one of the **Grand Challenges** identified by the National Nanotechnology Initiative.
- Chemical analysis at the nanometer scale** is needed in many important applications such as:

Nanostructured materials, including self-healing, multifunctional and biomolecular materials

Nanoelectronics

Energy conversion and storage, including photo-voltaic converters

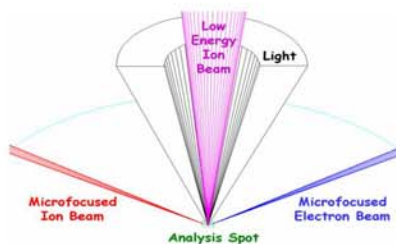
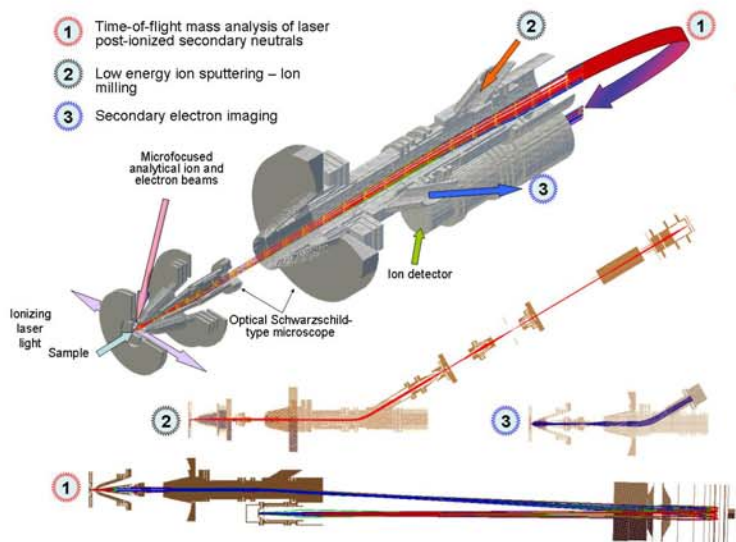
Quality control in manufacturing on the nanoscale

Many others...

- The ultimate goal is to develop a **3-Dimensional Laser Post Ionization Secondary Neutral Mass Spectrometry (LPI SNMS)** capable of addressing the needs of advance nanotechnology.

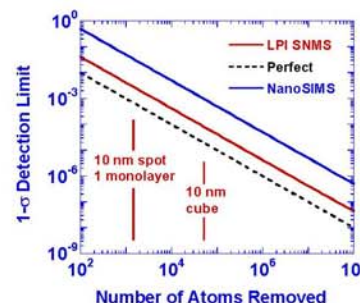
Major Accomplishments and Significance

- We have invented ion optics that maximize transmission of photo-ions through a time-of-flight mass spectrometer to the detectors.
- Based on this design, a **new generation** of LPI SNMS instruments with **the highest sensitivity and efficiency in the world** was developed.
- This new instrumentation has two modes of operation crucial for nanometer-scale analysis:
 - Dual beam operation** to **optimally combine** low energy ion sputtering with microfocused analytical probes (ion, electron or photon beams)
 - Secondary electron detection** to image analyzed samples using electrons generated by ion, electron or photon bombardment
- This novel ion optics also incorporate a new in-vacuum optical microscope with submicron resolution.



Dual beam operation:

Microfocused ion, electron and laser beams produce a 2D surface image. The 3rd dimension is depth obtained by eroding the surface with a low-energy, normally-incident ion beam, which minimizes roughness to optimize depth resolution.



Because of the limited number of atoms in nanometer-devices, instrument sensitivity is very important. The curve above shows the detection limit vs. sample size.

Current analytical capabilities:

Useful Yield ~ 20%

Mass resolution ~1600

Depth resolution – a few nm

Lateral Resolution:

50 nm with ion probe,

0.5 μ m with laser probe,

50 nm with electron probe

Future Directions

- In the near term, we will develop experimental methods to enable and to demonstrate 2D and 3D analyses with ~50 nm analytical resolution
- Lateral resolution will be further improved with addition of a new generation liquid metal ion source capable of supplying analytical spots of ~ 5 nm
- These advances will create a unique analytical tool capable of three-dimensional characterization of samples down to <10 nm

I. V. Veryovkin, W. F. Calaway, M. J. Pellin, *Nucl. Inst. Meth. A* 519 (2004) 353-362.